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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of Hariprasad Sreedharamurthy et al.
Serial No. 10/039,459
Filed November 7, 2001
Confirmation No. 1061

Art Unit 1765

For APPARATUS AND PROCESS FOR THE PREPARATION OF LOW-IRON
SINGLE CRYSTAL SILICON SUBSTANTIALLY FREE OF AGGLOMERATED
INTRINSIC POINT DEFECTS

Examiner Matthew J. Song

BRIEF FOR APPELLANTS

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West Group, Manual of Patent Examining Procedure, 8th Ed. (2003). 5, 9, 10

CASES

In re Cofer,
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BRIEF FOR APPELLANTS

This is an appeal from the final rejection of the above-identified application made in the Office action dated January 14, 2004. A Notice of Appeal was mailed on June 25, 2004.

I. REAL PARTY IN INTEREST

The real party in interest in connection with the present appeal is MEMC Electronic Materials Inc., owner of a 100 percent interest in the pending application.

II. RELATED APPEALS AND INTERFERENCES

Appellants are unaware of any pending appeals or interferences which may directly affect or be directly affected by, or have a bearing on, the Board's decision in the pending appeal.

III. STATUS OF CLAIMS

This application claims priority from U.S. provisional application Serial No. 60/258,296, filed on December 26, 2000. Claims 1-14 are currently pending. In a Response to Restriction Requirement filed on November 21, 2002, Applicant elected claims 1-14 for examination and withdrew claims 15-33 from consideration in a reply Office action dated March 21, 2003. A copy of the pending claims appears in the Appendix to this Brief.

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Claims 1-9 stand rejected under 35 U.S.C. §103(a) as being unpatentable over Holder et al.¹ Claims 10 and 14 stand rejected under 35 U.S.C. §103(a) as being unpatentable over Holder et al in view of Falster et al² and Kim et al.³ Claims 11-13 stand rejected under 35 U.S.C. §103(a) as being unpatentable over Holder et al in view of Falster et al and Kim et al as applied to claims 10 and 14 in view of Luter et al.⁴

IV. STATUS OF AMENDMENTS

No amendments have been filed after the final rejection.

V. SUMMARY OF THE INVENTION

The following summary is provided in accordance with MPEP §1206 and correlates claim elements to specific embodiments described in the specification. Consistent with MPEP §1206, the following summary does not in any manner limit claim interpretation. Rather, the following summary is provided only to facilitate the Board's understanding of the subject matter of this appeal.

The present invention is directed to a crystal pulling apparatus for producing a silicon single crystals grown having a reduced level of metallic contamination, in particular an apparatus for the preparation of low-iron impurity single silicon crystals (See page 1, lines 9-16).

Conventional crystal pulling apparatus often include graphite structural components. Impurities within these graphite structural components can evaporate and contaminate the crystal during grown. Because of this, graphite components within the hot zone of crystal pullers are commonly coated with a protective barrier layer, typically silicon carbide.

¹ WO 99/66108.

² U.S. Patent No. 5,919,302.

³ U.S. Patent No. 5,942,032.

⁴ U.S. Patent No. 5,922,127.

Recently, "closed" hot zone configurations have been incorporated into crystal pullers to allow the growth of agglomerated intrinsic point defect free crystals. These "closed" hot zone configurations include additional structural components in the hot zone such as upper, intermediate and lower shields in the region above the crystal melt. Typically, these additional components are located in closer proximity to the ingot and cause the ingot to be maintained at higher temperatures for longer periods of time. Significantly, the increased amount of structural graphite, the higher temperatures, the closer proximity of structural components to the growing ingot and melt, and the longer duration of the pulling process can contribute to an increased amount of iron diffusing into the crystal. Because of this increased iron diffusion, crystals grown in "closed" hot zone designs typically have iron concentrations near the peripheral edge (i.e., edge iron concentrations) which are at least 5 ppta to 10 ppta (parts per thousand atomic) and may be as high as 100 ppta.

The present invention solves this problem by making the structural components in the crystal growth chamber such that they comprise a substrate and a protective layer covering the surface of the substrate wherein the substrate comprises graphite and has a concentration of iron no greater than about 1.5×10^{12} atoms/cm³ and the protective layer comprises silicon carbide and has a concentration of iron no greater than about 1.0×10^{12} atoms/cm³ (See paragraph 0022 of the published application). Using the apparatus of the present invention, silicon ingots/wafers having an edge iron concentration below about 5 ppta (parts per thousand atomic) and even below about 0.8 ppta have been prepared (See paragraph 0024 of the published application).

VI. ISSUE

The issues presented on appeal are as follows:

A. Whether claims 1-9 are unpatentable under 35 U.S.C. §103 over Holder et al?

B. Whether claims 10 and 14 are unpatentable under 35 U.S.C. §103 over Holder et al in view of Falster et al and Kim et al?

C. Whether claims 11-13 are unpatentable under 35 U.S.C. §103 over Holder et al in view of Falster et al and Kim et al in view of Luter et al?

VII. GROUPING OF CLAIMS

Claims 1-14 stand or fall together.

VIII. ARGUMENT

A. Claims 1-9 are patentable under 35 U.S.C. §103 over Holder et al?

To render a claim obvious, the prior art reference (or references when combined) must teach or suggest all of the claim limitations.⁵

Claim 1 is directed to a crystal pulling apparatus for producing a silicon single crystal grown by the Czochralski process. The structural component comprises a substrate and a protective layer covering the surface of the substrate inside the growth chamber. The substrate comprises graphite which has a concentration of iron no greater than about 1.5×10^{12} atoms/cm³. The protective layer comprises silicon carbide and has a concentration of iron no greater than about 1.0×10^{12} atoms/cm³.

Holder et al. disclose a crystal pulling apparatus comprising a growth chamber and a structural component disposed within the growth chamber. According to Holder et al., the structural component comprises graphite and has a protective layer covering the graphite. Holder et al. disclose that the graphite has less than about 20 ppm total metals such as iron, molybdenum, copper, and nickel, and preferably has less than about 5 ppm total metals.⁶ Holder et al. also disclose that as the purity of the graphite increases, the amount of particle generation during high temperature heating decreases.⁷ Additionally, Holder et al. disclose that the protective layer may comprise

⁵ MPEP 2143.

⁶ Holder et al. (WO 99/66108) at page 7, lines 10-16.

⁷ Holder et al. at page 7, lines 16-18.

between about 99.9% to about 99.99% silicon carbide and between about 0.01% to about 0.1% silicon, which typically comprises about 1 ppma of iron.⁸

In contrast, Claim 1 requires that the concentration of iron in the substrates be **more than 10,000 times** lower than the preferred concentration allowed by Holder et al. In addition, the Office concedes that Holder et al. fail to disclose, teach or suggest coating a graphite substrate with a silicon carbide protective layer having a concentration of iron no greater than about 1.0×10^{12} atoms/cm³ as required by claim 1. Accordingly, Holder et al. fail to disclose or suggest the requirements of Applicants' claims.

To establish a *prima facie* case of obviousness there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference.⁹ In the present case, there is no suggestion to modify the disclosure of Holder et al. to require that the graphite substrate and the silicon carbide layer have concentrations of iron no greater than about 1.5×10^{12} atoms/cm³ and 1.0×10^{12} atoms/cm³, respectively. One possible source of such a suggestion to modify is the teachings of the prior art.¹⁰ Although Holder et al. are concerned with controlling iron contamination of silicon by iron evolved from structural components, they do not teach or suggest reducing the concentration of iron in structural components. Rather, Holder et al. teach controlling iron contamination of the silicon ingot by gettering or capturing evolved metal impurities.¹¹ Specifically, Holder et al. disclose two methods of gettering metal impurities such as iron by utilizing the high affinity of silicon for such contaminants. The first embodiment comprises overlaying a silicon carbide or glassy carbon protective layer with a silicon layer.¹² The

⁸ Holder et al. at page 10, lines 25-33.

⁹ MPEP 2142, Third Paragraph.

¹⁰ MPEP 2143.01 (*quoting In re Rouffet*, 149 F.3d 1350, 1357, 47 USPQ2d 1453, 1457-58 (Fed. Cir. 1998)).

¹¹ Holder et al. at page 4, lines 1-5; page 6, lines 15-22.

¹² Holder et al. at page 6, lines 8-15; and page 7, line 19 to page 8, line 6.

second embodiment comprises incorporating silicon with silicon carbide in a single protective coating.¹³ As described above, the treatment of iron concentrations in the graphite and silicon carbide disclosed by Holder et al. is largely superficial and is consistent with their solution of controlling iron contamination of the ingot by gettering. Thus, Holder et al. do not teach or suggest decreasing the concentration of iron in the graphite and silicon carbide protective layer below conventional levels.

Moreover, the proposition stated in the Office action that "purifying an old product is held to be obvious" under MPEP 2144.04 VII does not render these claim requirements obvious. This section of the MPEP specifically acknowledges that "purer forms of known products may be patentable," and directs the Office to consider the following factors to assess patentability:

- 1) whether the claimed composition has the same utility as closely related materials in the prior art, and
- 2) whether the prior art suggests the claimed form, or
- 3) whether the prior art suggests methods of obtaining the claimed form.

For claim 1 to be obvious, the claimed composition would have to have the same utility as closely related materials in the prior art and either the prior art would have to suggest the claimed form or the prior art would have to suggest methods of obtaining the claimed form. In the present case, all three factors taken separately or combined support a finding that the claimed subject matter is not obvious. With regard to the first factor, the crystal pulling apparatus of claim 1 has a different utility than a crystal pulling apparatus disclosed by Holder et al. According to Court of Customs and Patent Appeals in *In re Cofer*, cited in the MPEP, ". . . whether a given chemical compound or composition has the same usefulness as closely related materials may be an important consideration in determining obviousness under 35 U.S.C. 103."¹⁴ Specifically, the

¹³ Holder et al. at page 6, lines 8-15; and page 10, lines 15-24.

¹⁴ *In re Cofer*, 148 USPQ 268, 271 (CCPA 1966). See also *In re Bergstrom* 166 USPQ 256, 262 (CCPA 1970) ("Whether the claimed pure materials have the same usefulness or assortment of properties as the impure materials of the prior art . . . is but one of the factors to be considered in determining the obviousness under 35 U.S.C. § 103.").

crystal growing apparatus of claim 1 is used to produce a single crystal silicon ingot and wafers sliced therefrom that are substantially free of agglomerated defects and have a low degree of edge iron contamination (e.g., an apparatus comprising six low-iron structural components can produce silicon having an edge iron concentration that is less than about 5 parts per trillion atomic (ppta) and an average iron concentration that is less than about 3 ppta).¹⁵ Such silicon is produced, in part, by decreasing the cooling rate of the growing ingot and maintaining the ingot at temperatures that keep intrinsic point defects mobile for longer periods of time. This is accomplished, in part, by designing the apparatus to have a closed hot zone which contains more structural components than an open hot zone. The additional structural components insulate the ingot thereby decreasing heat loss from the ingot. The structural components, when growing silicon substantially free of agglomerated defects, are maintained at high temperatures for relatively long periods of time and this increases the propensity for iron to contaminate the ingot. In contrast to the claimed apparatus, a crystal pulling apparatus made of conventional structural components, such as the one described in Holder et al, cannot produce ingots that are substantially free of agglomerated defects without contaminating the silicon with an unacceptable amount of iron (e.g., that silicon will have average iron concentration of 5-10 ppta and an edge iron concentration as high as 100 ppta).¹⁶ In view of the fact that the crystal pulling apparatus of claim 1 produces silicon that is fundamentally and qualitatively different from silicon produced using a crystal puller made of conventional structural components, the crystal puller of claim 1 has a different utility than that disclosed by Holder et al. This different utility supports a conclusion that claim 1 is nonobvious under 35 U.S.C. 103.

With regard to the second factor, Holder et al. do not recognize the desirability of making a growth chamber of structural components having a substantially lower concentration of iron impurity, much less 10,000 times the lower concentration. Although Holder et al. disclose particle generation depends on graphite purity,¹⁷ this

¹⁵Application at page 13, lines 5-13.

¹⁶Application at page 6, lines 23-26.

¹⁷Holder et al. at page 7, lines 16-18.

characterization of conventional graphite cannot be fairly interpreted as a recognition or suggestion to reduce the concentration of metal contaminants to unconventional levels, such as less than about 1.5×10^{12} atoms/cm³. In fact, rather than suggesting a significant reduction in impurities, the entire specification of Holder et al. is directed to controlling iron contamination of a silicon ingot by gettering or capturing metal impurities evolved from structural components.¹⁸ Specifically, Holder et al. disclose two methods of gettering metal impurities such as iron by utilizing the high affinity of silicon for such contaminants. The first embodiment comprises overlaying a silicon carbide or glassy carbon protective layer with a silicon layer.¹⁹ The second embodiment comprises incorporating silicon with silicon carbide in a single protective coating.²⁰ As described above, the treatment of iron concentrations in the graphite and silicon carbide disclosed by Holder et al. is largely superficial and is consistent with their solution of controlling iron contamination of the ingot by gettering. Thus, Holder et al. do not recognize or suggest the high degree of purity for the carbon substrate and protective layer as required by claim 1. Rather, Holder et al., suggests that it is not necessary to reduce the iron concentration since the iron can be gettered by the protective coating.

With regard to the third factor, Holder et al. do not disclose any method for producing a structural component comprising a graphite substrate and a silicon carbide coating having the claimed iron concentrations. For example, claim 1 specifies that the graphite component has a concentration of iron that is no greater than about 1.5×10^{12} atoms/cm³. This concentration is over 10,000 times lower than the 5 ppm concentration of conventional graphite. However, Holder et al. do not provide any direction as to the manner in which such an increase in graphite purity could be attained.

In *Ex parte Stern*²¹, cited in MPEP 2144.04, the Board held the claimed homogenous (purified) human interleukin 2 to be obvious on the basis of conclusions analogous to the factors recited in the MPEP:

¹⁸Holder et al. at page 4, lines 1-5; page 6, lines 15-22.

¹⁹Holder et al. at page 6, lines 8-15; and page 7, line 19 to page 8, line 6.

²⁰Holder et al. at page 6, lines 8-15; and page 10, lines 15-24.

²¹13 USPQ2d 1379 (BPAI 1989).

2) The Office provided evidence the product itself was disclosed or suggested in the art: "Skilled workers in this particular art have sought to purify IL-2 to homogeneity and apparently failed." "...there is a recognition in the art of the desirability of purifying IL-2 to homogeneity." 13 USPQ2d 1381.

3) The Office presented evidence of prior art methods to make the claimed product: "Pestka discloses a process employing high performance liquid chromatography capable of purifying to homogeneity proteins exhibiting molecular weights in excess of 12,000." 13 USPQ2d 1381.

And with regard to the first factor, though not specifically discussed, apparently the Applicant failed to present evidence of any special utility beyond that of conventional IL-2. In the present situation, in contrast to the *Stern* situation, a) there is no evidence of record of any suggestion in the prior art of the presently claimed structure, b) there is no evidence of record of any suggestion in the prior art of how to make the claimed structure, and c) Applicants' specification explains in detail the unexpected advantage the invention provides of facilitating production of wafers that are substantially free of agglomerated defects and have a low degree of edge iron contamination. Accordingly, contrasting the facts of the *Stern* case to the facts of the present application underscores that Applicants' claimed invention cannot fairly be deemed to be obvious as a "mere purification."

Further guidance is provided by the decision in *In re Cofer*, cited in the MPEP. The CCPA reversed the Board's finding of obviousness because even though there was evidence of factor 1) common utility, there was no evidence of factor 2) suggestion in the art to make the enhanced compound, or factor 3) suggestion on how to make the enhanced compound. Similarly, in the present case the Office has not pointed to any 2) suggestion in the prior art to make the claimed enhanced structure, nor to any 3) suggestion in the prior art how to make the claimed enhanced structure. The present claims are therefore allowable for the same reasons as the claims in the *Cofer* decision cited in the MPEP.

With regard to the *Ex parte Gray* case cited in the Office action and in the MPEP, Applicants do not contest the proposition that "mere purity of a product by itself does not render the product unobvious." But in the present case, patentability is premised neither on the basis of "mere purity," nor on purity "by itself." The specific

requirements of the claims with regard to purity, as described in detail above, facilitate production of wafers that are substantially free of agglomerated defects and have a low degree of edge iron contamination. This is an unexpected advantage, namely, an entirely distinct realm of capacity not available with structures having only conventional purity. Moreover, the purity level required in applicants' claims cannot fairly be deemed to be "mere," as neither the level itself nor a method of achieving it is suggested in the art.

Still further, there is a lack of motivation to modify Holder et al.'s support coating to have as low an iron concentration as required by claim 1 because of the iron contamination problem addressed by Holder et al. is significantly different from the problem faced by the Applicants. The present invention is directed toward an apparatus used to produce silicon that is substantially free of agglomerated defects. Such silicon is produced, in part, by decreasing the cooling rate of the growing ingot and maintaining the ingot at temperatures that keep intrinsic point defects mobile for longer periods of time. This is accomplished, in part, by designing the apparatus to have a closed hot zone which contains more structural components than an open hot zone. The additional structural components insulate the ingot thereby decreasing heat loss from the ingot. Said structural components, when growing silicon substantially free of agglomerated defects, are maintained at high temperatures for relatively long periods of time and this increases the propensity for iron to contaminate the ingot. The Applicants discovered that acceptable iron levels in the ingot could not be achieved using structural components with conventional iron concentrations in the substrate and coating. The Applicants discovered that to decrease the amount of iron in such an ingot the concentration of iron in both the substrate and protective layer had to be dramatically reduced. To that end, the Applicants determined that iron concentrations within the substrate and protective layer had to be no greater than about 1.5×10^{12} atoms/cm³ and 1.0×10^{12} atoms/cm³, respectively. Holder et al. were not faced with reducing iron contamination under such demanding process conditions nor with the increased number of structural components of a closed hot zone. Thus, they were not faced with the same problems as the Applicants. As a result, Holder et al. were not

motivated to decrease the iron concentrations in conventional structural components let alone require the extremely low iron concentrations set forth in claim 1.

The Office also suggests that Larkin et al.²² teaches a method of forming silicon carbide having a non-crystal element concentration of less than about $8 \times 10^{13} \text{ cm}^{-3}$, which is a teaching of obtaining a purified silicon carbide crystal within the claimed range. However, the examiner disregards the fact that Larkin et al discloses a method of controlling the amount of impurity incorporation in a crystal grown by a chemical vapor deposition process, not by the Czochralski process as in the present invention. In fact the method and apparatus used in Larkin et al. is completely different than the present invention.

In view of the foregoing, the Office has failed to present a *prima facie* case of obviousness because the cited art fails to disclose, teach or suggest all the elements of claim 1. Specifically, the requirements of claim 1 that the concentrations of iron in the substrate and the protective layer be no greater than about $1.5 \times 10^{12} \text{ atoms/cm}^3$ and $1.0 \times 10^{12} \text{ atoms/cm}^3$, respectively, are nonobvious. In addition, there is no suggestion or motivation in the references themselves or in knowledge generally available to one of ordinary skill in the art to modify the reference.

Claims 2-9 each depend directly or indirectly from claim 1 and as such are submitted as patentable for the same reasons as set forth above and in view of the additional requirements which they specify. For example, claims 2-6 are patentable for the same reasons as claim 1 and are further patentable over the cited art because they require even lower concentrations of iron in the substrate or the protective layer. Claims 7 and 8 are further patentable because they further require that the protective layer have a specified thickness. Claim 9 is further patentable because it further requires that the protective layer cover the entire surface of the substrate.

In view of the foregoing, the Office has failed to present a *prima facie* case of obviousness because the cited art fails to describe or suggest a crystal pulling apparatus comprising a structural component that comprises a graphite substrate having a concentration of iron no greater than about $1.5 \times 10^{12} \text{ atoms/cm}^3$ and a

²² Larkin et al. (U.S. Patent No. 5,709,745).

protective layer that comprises silicon carbide and has a concentration of iron no greater than about 1.0×10^{12} atoms/cm³. As such, claim 1-9 are submitted as patentable over Holder et al.

B. Claims 10 and 14 are unpatentable under 35 U.S.C. §103 over Holder et al in view of Falster et al and Kim et al?

Claims 10 and 14 each depend directly from claim 1 as such are patentable over Holder et al. for the same reasons as discussed above with regards to claim 1. Specifically, Holder et al., fail to describe or suggest any apparatus comprising structural components having a substrate and protective layer such that the concentrations of iron in the substrate and the protective layer be no greater than about 1.5×10^{12} atoms/cm³ and 1.0×10^{12} atoms/cm³, respectively. Moreover, neither Falster et al nor Kim et al describe or suggest such an apparatus or even discuss any structural components having such iron concentrations. Indeed, the Office makes no such assertion. As such, Falster et al. and Kim et al., whether considered alone or in combination, fail to cure the deficiencies of Holder et al.

C. Claims 11-13 are unpatentable under 35 U.S.C. §103 over Holder et al in view of Falster et al and Kim et al in view of Luter et al?

Claims 11-13 each depend indirectly from claim 1 as such are patentable over Holder et al. for the same reasons as discussed above with regards to claim 1. Specifically, Holder et al., fail to describe or suggest any apparatus comprising structural components having a substrate and protective layer such that the concentrations of iron in the substrate and the protective layer be no greater than about 1.5×10^{12} atoms/cm³ and 1.0×10^{12} atoms/cm³, respectively. Moreover, none of the other cited references, Falster et al., Kim et al., or Luter et al. describe or suggest such an apparatus or even discuss any structural components having such iron concentrations. Indeed, the Office makes no such assertion. As such, Falster et al., Kim et al. and Luter et al., whether considered alone or in combination, fail to cure the deficiencies of Holder et al.

D. Conclusion

A *prima facie* case of obviousness has not been established pursuant to 35 U.S.C. § 103, because the cited art fails to disclose, teach or suggest all the elements of claim 1-14. For these reasons, and for those more fully stated above, Applicants respectfully request the Office's rejections be reversed and claims 1-14 be allowed.

* A check for \$770.00 is enclosed (\$340.00 for the appeal brief fee specified under 37 CFR 1.17(c) and \$430.00 for a two month extension of time). The Commissioner is hereby authorized to charge any additional fees which may be required to Deposit Account No. 19-1345.

Respectfully submitted



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APPENDIX
PENDING CLAIMS ON APPEAL

1. A crystal pulling apparatus for producing a silicon single crystal grown by the Czochralski process, the apparatus comprising:
a growth chamber; and
a structural component disposed within the growth chamber, the structural component comprising a substrate and a protective layer covering the surface of the substrate that is exposed to the atmosphere of the growth chamber, the substrate comprising graphite and having a concentration of iron no greater than about 1.5×10^{12} atoms/cm³, the protective layer comprising silicon carbide and having a concentration of iron no greater than about 1.0×10^{12} atoms/cm³.
2. The crystal pulling apparatus as set forth in claim 1 wherein the concentration of iron in the substrate is no greater than about 1.0×10^{12} atoms/cm³.
3. The crystal pulling apparatus as set forth in claim 1 wherein the concentration of iron in the substrate is no greater than about 0.5×10^{12} atoms/cm³.
4. The crystal pulling apparatus as set forth in claim 1 wherein the concentration of iron in the substrate is no greater than about 0.1×10^{12} atoms/cm³.
5. The crystal pulling apparatus as set forth in claim 1 wherein the concentration of iron in the protective layer is no greater than about 0.5×10^{12} atoms/cm³.
6. The crystal pulling apparatus as set forth in claim 1 wherein the concentration of iron in the protective layer is no greater than about 0.1×10^{12} atoms/cm³ of iron.
7. The crystal pulling apparatus as set forth in claim 1 wherein the protective layer is about 75 to about 125 μ m thick.
8. The crystal pulling apparatus as set forth in claim 1 wherein the protective layer is about 100 μ m thick.
9. The crystal pulling apparatus as set forth in claim 1 wherein the protective layer covers the entire surface of the substrate.
10. The crystal pulling apparatus as set forth in claim 1 wherein the structural component is adapted to reach a temperature of at least about 950 °C for a duration of at least about 80 hours and to be within about 3 cm to about 5 cm of the silicon single crystal or a silicon melt during the growth of the silicon single crystal.
11. The crystal pulling apparatus as set forth in claim 10 wherein the structural component is selected from the group consisting essentially of an upper heater, an upper heater shield, an intermediate heat shield, a lower heat shield inner reflector, a

lower heat shield outer reflector, a lower heat shield insulation layer, an upper insulation support and an upper insulation shield.

12. The crystal pulling apparatus as set forth in claim 11 comprising at least six structural components selected from the group.

13. The crystal pulling apparatus as set forth in claim 11 comprising at least eight structural components selected from the group.

14. A crystal pulling apparatus for producing a silicon single crystal grown by the Czochralski process, the apparatus comprising:

a growth chamber; and

a plurality of structural components disposed within the growth chamber that are adapted to reach a temperature of at least about 950 °C for a duration of at least 80 hours and to be within about 3 cm to about 5 cm of the silicon single crystal or a silicon melt during the growth of the silicon single crystal, each structural component comprising a substrate and a protective layer covering the surface of the substrate that is exposed to the atmosphere of the growth chamber, the substrate comprising graphite and having a concentration of iron no greater than about 1.5×10^{12} atoms/cm³, the protective layer comprising silicon carbide and having a concentration of iron no greater than about 1.0×10^{12} atoms/cm³.